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An Intelligent Power Utilization Strategy in Smart Building Based on AIWPSO

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Abstract

This paper presents a strategy for intelligent power utilization in smart building based on particle swarm optimization with adaptive chaotic inertia weights (AIWPSO) to minimize electric cost and maximize user's comfort. Suppose that photovoltaic (PV) generation, batteries, micro turbines, controllable loads and uncontrollable loads exist in smart building. The proposed AIWPSO algorithm used in solving the intelligent power utilization model can further improve the performance compared with PSO algorithm in terms of convergence speed and accuracy as well as the global searching ability because of the chaotic characteristics and adaptive nature provided by the success rate which can provide the state information of the swarm and help them adjust the inertia value for better position. The effectiveness of AIWPSO is evaluated and compared with the standard PSO, and the simulation results demonstrate the effectiveness of the proposed intelligent power utilization strategy, which can reduce electric cost and increase user's comfort through optimally operate power equipments and appliances according to self demand.

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Keywords: Smart Building, Intelligent Power Utilization, Particle Swarm Optimization, Adaptive Chaotic Inertia Weight

1. Introduction

Appliances such as refrigerators, washing machines, water heaters, air conditioning, lighting and other controllable or uncontrollable loads, as well as power source equipments such as photovoltaic power generation, batteries, and micro turbines exist in residential/commercial buildings[1] .

Smart meters, smart sensors, energy management unit and high-speed bi-directional communication will be widely used in residential/commercial buildings [2] with the support of Information and Communication Technologies (ICT). Meanwhile, a variety of retail policy such as real-time pricing, time-of-use (TOU), peak pricing are applied by power companies to encourage power end-users to participate in demand response projects. Furthermore, one can control and monitor the cycling, on/off, or mode switching of appliances wirelessly with an energy management system by deploying local area networks (LANs) and employing smart appliances. Intelligent Building is one of the fundamental components of the smart grid, where exist a variety of distributed power sources, controllable loads, increasingly demand of electricity services, as well as the application of modern information and communication technologies. [3].

Currently, a variety of methods have been proposed to realize intelligent power utilization, which

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are mainly focus on robust renewable power management, reducing energy costs and improving user comfort. The optimal operation by controllable loads considering insolation forecasted error is studies in [4], fuzzy logic is used to forecast weather conditions and PV output and then establish intelligent power utilization strategy; an appliance commitment method for household load scheduling considering users' comfort setpoint temperature is presented in [5]; Demand-side energy management in smart power grids for robust renewable power management is investigated in [6]; A power consumption scheduling method to minimize the expected cost with price uncertainly is presented in [7]; A state-queueing model to analyze the price response of controllable loads is developed in [8].

Give the above background, an intelligent power utilization strategy is proposed in this paper. Load in smart buildings are divided into two parts: controllable loads and uncontrollable loads as above. Photovoltaic generation, battery, micro turbines and other power equipment are assumed exist in smart building. In the proposed power utilization strategy, electricity costs are minimized while ensuring users' comfort. A mathematical model is built for intelligent power utilization, and the model is solved by employing AIWPSO, which has better convergence performance compared with ordinary PSO. The simulation results demonstrate the effectiveness and features of the proposed strategy.

2. Intelligent power utilization strategy

2. 1 Problem description

It's supposed that there are power source equipments, such as photovoltaic panels, micro turbines, batteries, etc, and appliances, such as dishwashers, water heaters, air conditioners, batteries, etc., in a smart building. Battery is an energy storage facility which should charge at a lower electricity price, and when price get higher or grid failure, it should discharge power. The energy management system send signals to the power source equipments and appliances to adjust the operation status.

A diagrammatic sketch of intelligent power utilization in smart building is shown in Fig.1, the involved variables are P_{Lt}, P_{pvt}, P_{Bt}, P_{it} and PG. P_{Lt} is uncontrollable load, such as lighting appliances; P_{Hpt} is controllable load, it's electric water heater in this paper; P_{pvt} is PV output, it is a micro-power in buildings; P_{Bt} is charge and discharge power of an energy storage device in buildings, such as batteries; P_{it} is the access point power flow; PG is output of micro turbine.

2.2Dynamic model of controllable load

The thermal dynamic model of water heaters can be described by differential equations, hot water temperature at time $k+1$ is as follows:

$$H_{k+1} = H_{ek} + S_k QR - (H_{ek} + S_k QR - H_k) exp\left[-\left(t_{k+1} - t_k\right)/\left(RC\right)\right] \quad (1)$$

where S_k is on/off signal, S_k=1 when heater turns on; otherwise, S_k=0. H_{k+1} is hot water temperature at time $k+1$, H_{ek} is outdoor temperature at time k; Q, R, C is electric water capacity, thermal resistance, thermal capacity, respectively. t_{k+1}- t_k is simulation time step. The simplified equivalent parameters, C(863.4kWh/℃), R(1.52℃/kW), and Q (4kW), reflect the main features of the hot water temperature and effectively reduce the measurement difficulty. The capacity of the water heater is 189.25L in this paper and the real measurement data are collected in the Pacific Northwest Grid Wise Testbed project.

The temperature and required heating power at time k:

$$P_k = m_k c(H_k - H_0) \quad (2)$$

where m_k (kg) is the quality of water to be heated, c is the specific heat capacity of water heater, H_k is hot water set temperature, H_0 is environment temperature. The control variable of electric water heater is setpoint temperature. Power consumption of water heater at time k:

$$P_{TCL}(k) = \eta_k P_k S_k \quad (3)$$

where η_k is the energy conversion efficiency, it's 2.6 in this paper. The demand power is calculated according to hot water usage using (2) (3), and the heating time is available.

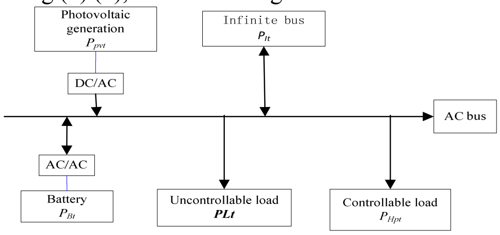

Figure 1. Diagrammatic sketch of intelligent power utilization

2.3 Mathematical model of intelligent power utilization

In this section, an optimization strategy for intelligent power utilization in smart building is proposed to minimize the electric cost while ensuring users' comfort. The water heater should compromise the conflict of power charge and use comfort which refer to the temperature and quantity of hot water, if the temperature of hot water is too high or too low, or there is not enough hot water when in need.

Objective function:

$$Min\ F=price_t * P_{it} + \sum_{i=1}^{n} C_i(P_{Gi}) \tag{4}$$

The first part of the objective function is money users need to pay to the grid for using electric, $price_t$ is the electric price at time t and P_{it} is the power usage at time t, the second part is the cost of micro gas turbines.

Constraints：

1) Constraint of interconnection point power flow:

$$B_{Imin}<P_{it}<B_{Imax} \tag{5}$$

2) Constraints of battery's operation:

$$CB_{it} = CB_0 + \sum_{i=1}^{t} P_{Bi}, t = 1,2,\text{L}\ ,T \tag{6}$$

$$|P_{Bat}|<P_{Bmax} \tag{7}$$

$$C_{Bmin}<C_{Bat}< C_{Bmax} \tag{8}$$

3) Constraints of energy balance:

$$P_G + P_{It} + P_{Bt} + P_{pvt} - P_{Hpt} = P_{Lt}, t = 1,2,\cdots,T \tag{9}$$

4) Constraints of micro turbine's operation:

$$P_{Gj\min} \le P_{Gj} \le P_{Gj\max}, j = 1,2,\text{L}\ ,\text{m} \tag{10}$$

$$C_j(P_{Gj}) = \alpha + \beta \cdot P_{Gj} + \gamma \cdot P_{Gj}{}^2, j = 1,2,...,\text{m} \tag{11}$$

where T is time section (24 hours); P_{It} is interconnection point power flow; B_{Imin} is minimum interconnection point power flow; B_{Imax} is maximum interconnection point power flow; P_{Bat} is charge/discharge power of battery; P_{Bmax} is charge/discharge power maximum value of battery; C_{Bat} is remaining energy capacity of battery; C_{Bmin} is minimum value of battery capacity; C_{Bmax} is maximum value of battery capacity; $P_{Gj\min}$ is minimum output of micro turbine j; $P_{Gj\max}$ is Maximum output of micro turbine j; $Price_t$ is day-ahead electric price at time t; m is the number of micro turbines in smart building.

P_{pvt} is PV generation, it can be calculated by:

$$P_{pvt} = \eta S_\alpha I_\alpha (1\text{-}0.005(t_0\text{-}25)) \tag{12}$$

where η is the conversion efficiency of PV array(%), S_α is the array area (m^2), I_α is the solar radiation (kW/m^2), t_o is the outside air temperature.

2.4 Algorithm

In this section, AIWPSO, one of the optimization algorithms, is described. The success rate has the characteristic of chaos and adaptability which provide more state information in the search process. AIWPSO can improve the global search ability and effectively jump out of local optimum, then reach the accurate, fast convergence compared to the standard PSO. AIWPSO [9] has adaptive chaos inertia weight which can monitor the search space and change the inertia weight value based on swarm success rate. It can properly adapt the value of the inertia weight in the static and dynamic environment using (13).The best particle was mutated by adding a Gaussian noise with zero mean standard deviation to one of its randomly chosen dimension and used to replace the worst particle at the end of each generation to improve on the exploration of the optimal method.

$$\omega_t = (\omega_{start} - \omega_{end})((T_{\max} - t)/T_{\max}) + \omega_{end} \times z \qquad (13)$$

$z = 4 \times SR \times (1 - SR)$ and SR is the success rate, which is computed using (11) at time t.

$$SR_t = \sum_{i=1}^{n} succ_t^i / n \qquad (14)$$

$$succ_t^i = \begin{cases} 1 & f(Pbest_t^i) < f(Pbest_{t-1}^i) \\ 0 & f(Pbest_t^i) \geq f(Pbest_{t-1}^i) \end{cases}, t = 1,2,\mathrm{L}\ ,T\ , i = 1,2,\mathrm{L}\ ,\mathrm{n} \qquad (15)$$

where $pbest_i$ is the current best position of particle i at generation t and $f(.)$ is the function to be optimized, n is the popsize of SR, $SR \in [0,1]$, it is the percentage of the particle with improvement infitness in the last iteration.

SR reflects the state of the particle swarm and decides feedback coefficient of inertia weight at each generation, it is set at 0 when no particle succeeds to improve its fitness. When all the particles succeed to improve their position, SR is set at 1.

The calculation step of the algorithm is as follows:

Step1:Initialize randomly, generates a two-dimensional array (p, d), p is the swarm size, d is the problem dimension, d=24 in this paper; Set $x_i = (x_1,...,x_d)$ and $v_i = (v_1,...,v_d)$ for all particles; determine particles of micro gas turbine using equal incremental law [10];

Step2: Evaluate $f(x_i)$ in d variables and get $pbest_i$ (i=1,...,p), $gbest_i$ is the best of $pbest_i$ (i=1,..., p);

Step3: without reaching the maximum iteration, set $succ$ = 0, begin loop for p times, otherwise end computing. Calculate w using (10), update v_i and check for velocity boundaries, update w using (13) or (16);

Step4: update x_i for particle and validate for position boundaries;

Step5: If $f(x_i) < f(pbest_i)$, set x_i as $pbest_i$; if $f(x_i) < f(gbest_i)$, set x_i as $gbest_i$,, $succ = succ + 1$;

Step6: t=t+1; go back to Step 3.

3 Numerical example and results

Assuming the day ahead electric price of 24 hours, these data correspond to the energy prices of the Spanish area of the electricity market of the Iberian Peninsula on Monday July 5, 2010. 2 micro turbines exist in the smart building, the cost coefficients of them is shown in Table 2; controllable and uncontrollable loads are shown in Fig.2.

TABLE I. COST COEFFICIENTS OF MICRO TURBINES

No.	***A***(€)	***B***(€/kWh)	***Γ***(€/kWh^2)
1	0.22	0.01	0.00089
2	0.24	0.007	0.001

3.1 The impact of renewable energy penetration

Penetration rate of renewable energy refers to the percentage of renewable energy of the total energy .Two cases have been implemented to study the impact of renewable energy on intelligent power utilization in smart building, case A has 9 photovoltaic panels and case B has 3 photovoltaic panels. The hot water setpoint temperature is 60℃in both cases.

The convergence curve of objective function of case A and B, The final value in case A is much less than that of case B because of larger quantity of PV output, which suggest that we can reduce electric cost by increasing penetration rate of renewable energy. Compare the final value of AIWPSO and PSO, AIWPSO has a better convergence which demonstrates the effectiveness of the proposed algorithm.

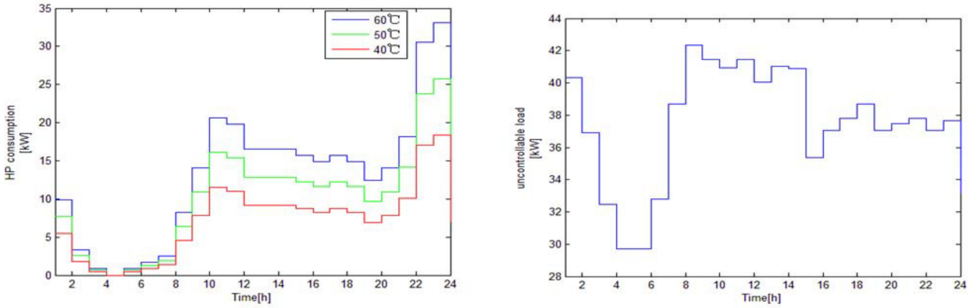

Figure 2. Controllable load(left) uncontrollable load(right)

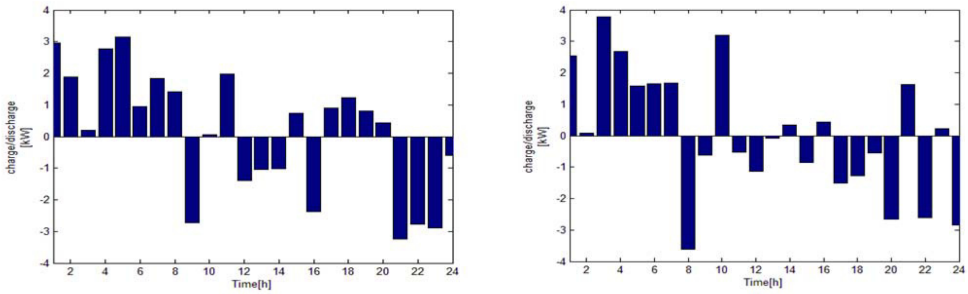

Figure 3. Charge/discharge of battery (case A(left)) (case B(right))

Fig.3 (left) shows the charge/discharge of battery of case A while Fig.4(right) is for case B. We can find from Fig. 5that, the battery will charge when electric price gets lower or less load connected. Meanwhile, it will discharge when electric price get higher or more load connected to the power system.

3.2 The impact of setpoint temperature of hot water

We implement case C with the setpoint temperature is 40℃ and keep the other variables the same with case A. The convergence curve of objective function of case C. The final value of case C is much less than that of case A, which demonstrate that we can reduce the electric cost by decreasing the set temperature of hot water.

3.3 The impact of outdoor temperature

The outdoor temperature affects electric cost by affecting the initial temperature of the water in the pump. Keeping the other variables the same, the outside temperature is set at 25℃ for case D, compare it with case A. The final value of case D is much less than that of case A, which demonstrates that higher outdoor temperature can help reduce the electric cost in some case.

4 Discussion and conclusion

This paper presents a mathematic model for intelligent power utilization in smart building, and a new algorithm, AIWPSO, is proposed for solving the model. The new algorithm with adaptive chaotic inertia weights has faster and better searching ability in global searching.

The simulation system demonstrates that this proposed intelligent electric power usage strategy is able to effectively reducing electric cost and increasing users' comfort. When electric price gets higher or more load connected to the power system, the micro turbines will decrease the output and the battery will discharge; meanwhile, when electric price gets lower or less load connected to the power system, the micro turbines will increase the output and the battery will charge; The electric cost can be decreased by decreasing the setpoint temperature of hot water.

Power consumption and power fluctuation arise from the penetration of PV in the smart building are smoothed by achieving the proposed intelligent power utilization strategy. Furthermore, we show the concept of the smart building introduced in all-electrification houses using controllable loads and simplify the central challenge for achieving load control: first, to achieve desirable aggregated power consumption patterns, and second, to maintain acceptable end-use performance.

The future work should consider the communications infrastructure in the design of any control paradigm, and compare the centralized, hierarchical, and distributed controllers.

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References

[1]D. S. Callaway, I. A. Hiskens. Achieving Controllability of Electric Loads. Proceedings of the IEEE , 2011, 99(1): pp.184-199

[2]P. Palensky, D. Dietrich, "Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads," *IEEE Trans. Industrial Informatics*, vol.7, pp.381-388, Aug. 2011

[3]George Koutitas. "Control of Flexible Smart Devices in the Smart Grid," *IEEE Trans. Smart Grid*, vol.3, pp.1333-1343, Sept, 2012:

[4]K. Tanaka, K. Uchida, T. Goya, et al. "Optimal Operation by Controllable Loads Based on Smart Grid Topology Considering Insolation Forecasted Error," *IEEE Trans. on Smart Grid*, vol.2, pp.438-444, Sept, 2011,

[5]P. Du, N. Lu. "Appliance Commitment for Household Load Scheduling," *IEEE Trans. Smart Grid*, vol.2, pp. 411-419, June,2011 :

[6]S. Bashash, H. K. Fathy. "Modeling and Control of Aggregate Air Conditioning Loads for Robust Renewable Power Management. " *IEEE Trans. Control Systems Technology*, vol.2, pp.1318-1327,July,2013

[7]T. T. Kim, H. V. Poor. "Scheduling Power Consumption With Price Uncertainty". *IEEE Trans. Smart Grid*, vol.2, pp. 519-527,Sept, 2011,

[8]N. Lu, D. P. Chassin. "A state-queueing model of thermostatically controlled appliances," *IEEE Trans. Power Systems,* vol.19, pp.1666-1673,Aug, 2004:

[9]M. A. Arasomwan, A. O. " Adewumi. On adaptive chaotic inertia weights in Particle Swarm Optimization. In: IEEE Symposium on Swarm Intelligence (SIS), 2013: pp. 72-79

[10]A. J. Wood and B. F. Wollenberg, " Power Generation, Operation, and Control, " 2nd ed. New York: Knovel, 1996

Biography

Jun Xie received the B.Eng. and Ph.D. degrees in Electrical Engineering from Hohai University, China, in 2002 and 2007, respectively. From May 2007 to April 2010, he held research positions with the Department of Electrical Engineering, Zhejing University, and the Department of Electrical and Electronic Engineering, the University of Hong Kong. He has been with the faculty of Nanjing

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